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Original Research

Cold Storage Influences Postharvest Chilling Injury and Quality of Peach Fruits

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ABSTRACT

Peach (*Prunus persica* L.) fruits exhibit limited postharvest shelf and storage life due to rapid softening. Therefore, in the present study effect of cold storage was investigated on postharvest chilling injury (CI) and fruit quality during ripening following cold storage on five peach cultivars including 'Peach Select No. 3' (PS-3), 'Florida Gold' (FG) and 'Florida King' (FK) as early season maturing, and 'Indian Blood' (IB) and 'Maria Delezia' (MD) as late season maturing cultivars. Peach fruits harvested at commercial maturity were ripened at ambient conditions following cold storage for 0, 10 and 20 days at 0±1 °C with 80±5% RH. Data regarding peach fruit quality parameters and incidence of CI were recorded at fully ripe eating soft stage. Results indicated that apart from the cultivars, fruit weight loss, levels of soluble solid content (SSC) and sugars increased as the storage period was progressed. However, fruit firmness, titratable acidity (TA), and ascorbic acid content significantly reduced during cold storage. Among early season maturing peach cultivars, fruits of 'FG' and among late season maturing peach cultivars, fruits of 'MD' showed better postharvest shelf life and fruit quality during ripening following cold storage. The highest SSC and SSC: TA ratio were observed in 'FG' peach fruits; however, these fruits exhibited 50% and 75% CI after 10 and 20 days of cold storage, respectively. During first 10 days of cold storage, 'PS-3' peach fruits showed better taste with higher fruit firmness and ascorbic acid content, however, later on the highest level of CI was observed in these fruits. Among all the tested peach cultivars, the 'IB' peach fruits showed higher fruit firmness, lower weight loss, as well as acceptable biochemical fruit quality (SSC, SSC; TA, ascorbic acid content, total sugars) during 20 days of cold storage without showing any symptoms of CI.

Keywords: *Chilling injury, low temperature storage, fruit quality, peach cultivars.*

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INTRODUCTION

Peach (*Prunus persica* L. Batsch) is a leading summer stone fruit crop cultivated commercially in temperate regions throughout the world. Presently, it is cultivated in over seventy countries in the world with about 18 million tons of production (FAOSTAT, 2016). At present, peach is mainly cultivated in Khyber Pakhtunkhwa (Swat, Dir, Bunir, Chitral, Peshawar, Hazara and South Waziristan), Balochistana (Quetta, Pishin, Loralai, Qilla Saifullah, Qilla Abdullah, Mastung and Kalat) and Punjab (Murree, Chakwal, Attock, Khushab and Soon Valley) in Pakistan, on an area of about 16 thousand ha with production of 71 thousand tons (Anonymous, 2016). Important cultivars of peach grown in the Pakistan are 'Florida King', 'Florida Gold', 'Early Grand', 'Spring Crest', 'Flam Crest', 'Elberta', 'Suwannee', 'Durbin', 'Sun Glow', 'Coronet', 'Indian Blood' and 'Maria Delezia' (Hussain, 2010).

Peach is a climacteric fruit which exhibits rapid rise in respiration rate and ethylene production during ripening. Due to high perishability, it has very limited shelf and storage life after harvest (Lill et al., 1989). This short postharvest life reduces its marketing with considerable reduction in the price and profit to the growers. Previously various techniques have been used by researchers to delay the postharvest ripening and extend the storage life of nectarine or peach fruits such as postharvest heat treatment (Obenland et al., 2005); cold storage (Manganaris et al., 2006; Ullah et al., 2015), controlled atmosphere storage (Uthairatanakij et al., 2005), modified atmosphere storage (Akbudak and Eris, 2004), exogenous application of calcium (Manganaris et al., 2005a, 2006), *Aloe vera* gel (Garner et al., 2001; Tareen et al., 2017), salicylic acid (Tareen et al., 2017), nitric oxide (Han et al., 2018), 1-MCP (Liguori et al., 2004; Ullah et al., 2016), and edible coatings (Ahmed et al., 2009) with varying success depends upon the cultivars, storage environment or concentrations of the treatments applied. Under low temperature storage conditions, nectarine fruits are highly susceptible to various physiological disorders including internal browning, woolliness and CI (Manganaris et al., 2005b).

Presently, rapid increase in the health-related disorders including chronic oxidative stress related diseases like cancer, inflammation, cardiovascular, and aging related problems have increased the attractions of consumers for consumption of food

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rich in anti-oxidants (Huang at el., 2005). Peach has been found to be highly nutritious fruit, contains sufficient amount of minerals (calcium, phosphorus, iron and potassium), vitamins (vitamin A, B1, B2, niacin) and anti-oxidants (ascorbic acids). Due to increased awareness among consumers about health promoting benefits of fruits, in recent years they are more curious about their nutritive quality specially to get maximum nutritional benefits by consuming fruits. Therefore, along with many other fruit crops, the amount of individual dietary anti-oxidants including total carotenoids, ascorbic acid and total anti-oxidants have also been determined in some commercial peach cultivars (Gil et al., 2002). However, very little is known about the effects of different seasons of fruit maturity on peach fruit quality, which warrants further investigations.

Being highly perishable fruit, it has very limited shelf and storage life which limits its export to distant markets. In recent years, the productivity of peach has been increased in Pakistan due to the establishment of new orchards with the introduction of high yielding cultivars. Production of peach has been increased as compared to other fruits, but the growers are discouraged due to its improper postharvest handling which reduces its price and value. Moreover, very little information is available about its ripening and overall postharvest potential of different promising locally grown peach cultivars. Moreover, no work has been reported in Pakistan on the shelf life characteristics and physico-chemical changes during the ripening and storage of commercial peach cultivars. Low temperature storage is recommended to delay ripening process, minimize physiological disorders and prevent degradation that hamper the quality of the produce. Therefore, there is need to explore the storage potential of different commercial peach cultivars for fresh consumption in domestic as well as export markets. Hence the present study was conducted to compare the ripening behaviour, shelf life and physico-chemical quality characteristics of different peach cultivars following cold storage.

MATERIALS AND METHODS

Plant Material

The fruits of early season maturing peach cultivars, 'Florida King' (FK), 'Peach Selecl. No. 3' (PS-3) and 'Florida Gold' (FG) were harvested from Horticultural Fruit Tree Research Station, (32°33'51.6"N; 72°08'28.2"E), Noshehra, Soon Valley, District Khushab; and of late season maturing cultivars 'Maria Delesia' (MD) and 'Indian Blood' (IB) were harvested from a commercial orchard in Swat (34°40'05.5"N; 72°13'52.4"E), Khyber Pakhtunkhwa at commercial maturity stage. After harvest, these fruits were transported in air-conditioned transport to Postharvest Laboratory, Institute of Horticultural Sciences, University of Agriculture, Faisalabad for further study. On arrival in the laboratory, 120 uniform sized fruits, free from any symptoms of physical injury, diseases and insect pests attack were sorted out and further divided into two groups to conduct following two experiments.

Experiment I: Fruit Ripening at Ambient Conditions

In the first study, half of the fruits (60) were kept in the laboratory for ripening at 30±2 °C with 60±5% RH. Data were collected regarding fruit weight loss, fruit firmness, SSC, TA, SSC: TA, ascorbic acid, sugars (total, reducing and non-reducing) contents during ripening on daily basis up to five days. This experiment was designed with completely randomized design with two factors (cultivars and ripening days) having factorial arrangement with three repetitions.

Experiment II: Fruit Ripening Following Cold Storage

In the second study, other half of the fruits (60) were kept in cold storage at 0±1 °C + 80-85% RH for 20 days. Fruit physico-chemical quality parameters were studied after 2 days of ripening at ambient conditions (30±2 °C with 60±5% RH) following cold storage for 0, 10 and 20 days. This experiment was also conducted under completely randomized design with two factors having factorial arrangement, repeated thrice.

Parameters Studied

Determination of CI

CI in the peach fruits was determined by visual observations, using a hedonic scale ranging from 1 to 5. Where: 1 = nil (no fruit affected with CI), 2 = 25% fruit affected with CI, 3 = 50% fruit affected with CI, 4 = 75% fruit affected with CI, 5 = 100% fruit affected with CI.

Fruit Weight Loss (%)

Fresh fruit weight loss was determined in percent by assessing the initial fruit weight at the beginning of the study and final at the end of storage period or ripening period.

Fruit Firmness

Fruit firmness was determined by using hand held penetrometer (Fruit Test™, Wangner Instruments, Greenwich, CT, USA). A thin slice of fruit skin was removed from two equatorial sides of each fruit and probe of penetrometer was inserted into flesh of fruit and average reading was expressed as newton (N).

Determination of SSC, TA and SSC: TA ratio

SSC of each experimental sample was determined by placing 1-2 drops of fruit juice on the prism of a hand held digital refractometer (RX 5000, Atago, Japan) and expressed as °Brix at room temperature. To determine TA of fruit juice sample, 10 mL fruit juice was taken in a 100 mL conical flash, it was further diluted (1:4) with distilled water and titrated against 0.1 N NaOH by using 2-3 drops of phenolphthalein ($C_{20}H_{14}O_4$) as an indicator and was expressed as percent malic acid. SSC: TA ratio was determined by dividing SSC with corresponding value of TA (Khan and Singh, 2009).

Determination of Ascorbic Acid Contents

Method reported by Khan and Singh (2009) was used for the determination of ascorbic acid contents in pulp tissues of peach fruits and was expressed as mg 100 g^{-1} fresh weight.

Determination of Sugars

Sugars including total, reducing and non-reducing were estimated from the juice samples of the experimental peach fruits by using the method reported by Shafiq et al. (2011) and were expressed as per cent (%).

Statistical Analysis

Data were analysed under completely randomized design with factorial arrangements i.e. effects of cultivars, storage period or ripening period and their interactions were evaluated by LSD test at 5% significance level. The data were statistically analysed with Statistix® software version 8.1 (Tallahassee, FL, USA).

RESULTS

Fruits of all the cultivars exhibited sharp rise in their weight loss with increase in the period of fruit ripening (Fig. 1A). The fruits of peach cultivar 'IB' showed the minimum weight loss followed by those of 'FK' and 'PS-3'. Fruits of peach cultivar 'MD' exhibited the highest weight loss (26%) followed by those of 'FG' (23%). Fruit weight loss in 'FK', 'PS-3' and 'IB' peach fruits valued as 18, 19 and 20%, respectively. Following 10 and 20 days of low temperature storage 'MD' peach fruits exhibited the maximum weight loss i.e. 15.5% and 5.4%, respectively (Fig. 2A); whereas, 'PS-3' fruits showed the minimum weight loss after 10 and 20 days of storage. During fruit ripening 'PS-3' fruits exhibited sharp rise in weight loss and at full ripe stage following low temperature storage, the weight loss was highest in 'PS-3' in contrast to all other peach cultivars. Fruit firmness of all peach cultivars reduced with increase in fruit ripening period before and after low temperature storage. During fruit ripening before storage the maximum reduction in fruit firmness was observed in fruits of peach cultivar 'FG' (12.5 N), as compared to all other peach cultivars (Fig. 1B). At fully ripe stage, fruits of peach cultivar 'PS-3' were firmer in contrast to other cultivars. During low temperature storage 'MD' peach fruits exhibited the maximum flesh softening (Fig. 2B). Following low temperature storage and fruit ripening the 'IB' peach fruits exhibited the maximum fruit firmness, as compared to all cultivars (Fig. 2B). During fruit ripening CI was not observed in any cultivar. However, all peach cultivars exhibited CI during low temperature storage and ripening following storage (Fig. 2C). CI increased slowly during cold storage, while the maximum increase was observed at ripening following low temperature storage. Peach cultivar 'PS-3' exhibited the highest CI during cold storage and 'FG' in ripe fruits following cold storage; whereas, minimum CI was observed in peach cultivar 'IB' (Fig. 2C).

As cold storage period progressed, SSC and SSC: TA ratio of fruits increased; whereas, TA reduced (Fig. 3). Peach cultivar 'FG' exhibited the maximum SSC and SSC: TA ratio during fruit ripening before cold storage (Fig. 3A and 3C). At ripe stage, before and following cold storage, late maturing peach cultivars i.e. 'MD' and 'IB' showed higher acid content in comparison to early maturing cultivars ('FK', 'PS-3', and 'FG') (Fig. 3B and Table 1). Cold storage did not influence SSC of the fruits. However, the peach cultivars 'FG' and 'MD' showed higher SSC following 10 and 20 days of cold storage (Table 1). Peach cultivar ''FG showed higher SSC: TA ratio in ripe fruits before and following 10 and 20 days of cold storage (Table 1).

During fruit ripening different maturing peach cultivars exhibited significant differences in levels of reducing, non-reducing and total sugars (Fig. 4). Overall level of sugars

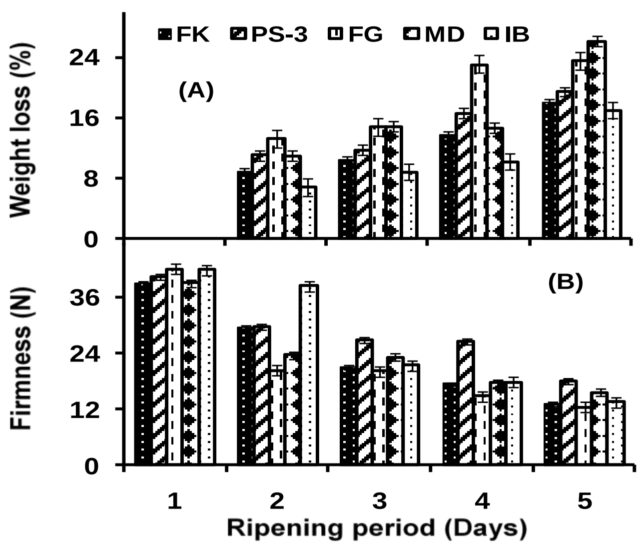

Figure 1: Changes in weight loss (A) and fruit firmness (B) during fruit ripening of different peach cultivars at ambient temperature. Vertical bars represent ±SE of means for three replicates.

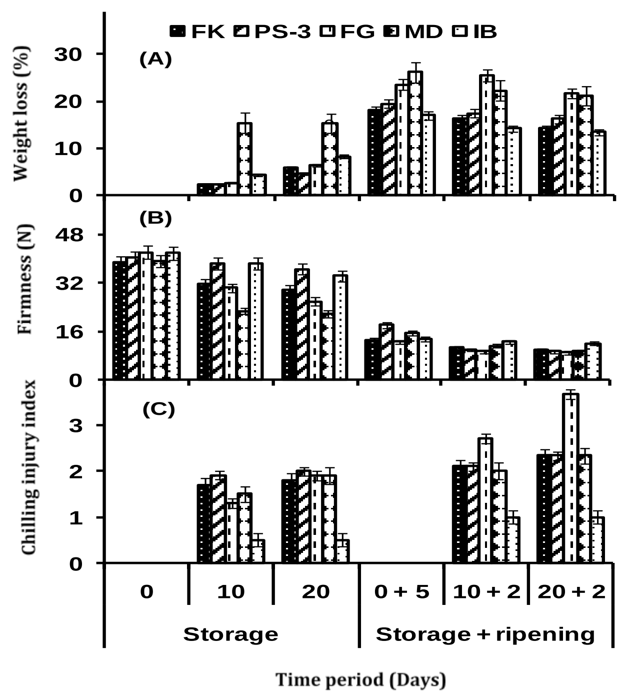

Figure 2: Weight loss (A), fruit firmness (B) and chilling injury of different peach cultivars following cold storage and fruit ripening. Vertical bars represent ±SE of means for three replicates.

Table 1: SSC, TA, SSC: TA ratio, reducing sugars, non-reducing sugars, total sugars and ascorbic acid content of different peach cultivars following cold storage and fruit ripening.

Cultivar	Storage + ripening period (days)	Maturity	SSC (%)	TA (%)	SSC:TA (Ratio)	Reducing sugars (%)	Non-reducing sugars (%)	Total sugars (%)	Ascorbic Acid (mg 100 g^{-1})
FK	0 + 5	Early	10.5 d	0.62 b	21.35 c	1.9 b	7.3 ab	9.2 ab	4.3 ab
PS-3		Early	13.3 bc	0.60 b	21.00 c	2.5 ab	8.5 a	11.0 a	3.5 bc
FG		Early	12.6 c	0.60 b	24.50 bc	2.0 b	5.6 b	7.6 bc	3.5 bc
MD		Late	14.7 b	0.70 a	18.00 d	1.9 b	5.1 bc	7.0 c	2.9 c
IB		Late	12.6 c	0.70	18.00 d	2.9 a	4.8 c	7.7 bc	2.9 c
FK	10 + 2	Early	12.6 c	0.53 c	25.53 bc	2.1 ab	3.7 d	5.8 e	3.9 b
PS-3		Early	13.5 b	0.54 c	25.31 bc	1.8 b	3.9 d	5.7 e	4.9 a
FG		Early	13.7 b	0.52 c	27.76 b	1.9 b	4.5 c	6.4 d	3.7 b
MD		Late	14.4 b	0.65 ab	20.10 c	1.9 b	8.7 a	10.6 a	1.9 d
IB		Late	13.1 bc	0.68 a	17.35 d	2.0 ab	5.4 bc	7.4 c	2.4 cd
FK	20 + 2	Early	13.2 bc	0.42 d	31.43 a	2.5 ab	3.7 d	6.2 de	3.9 b
PS-3		Early	11.7 cd	0.41 d	28.54 b	1.6 c	4.6 c	6.2 de	2.9 c
FG		Early	13.6 b	0.41 d	33.17 a	1.6 c	7.3 ab	8.9 b	4.2 ab
MD		Late	16.9 a	0.59 b	28.70 ab	2.0 b	5.8 b	7.8 bc	2.1 cd
IB		Late	13.6 b	0.48 cd	28.40 ab	2.7 a	3.9 d	6.6 d	2.4 cd
$P \leq (0.05)$									
Cultivars			0.29	0.14	0.42	0.14	0.25	0.86	0.25
Days			0.31	0.13	0.35	0.18	0.36	0.64	0.31
Cultivars x Days			0.62	0.18	1.12	0.53	1.12	2.13	0.56

increased with increase in fruit ripening period (Fig. 4A). Peach cultivar 'IB' exhibited the highest amount of reducing sugars, as compared to all other cultivars (Fig. 4A). At fully ripe stage, levels of non-reducing and total sugars were the maximum in peach cultivar 'PS-3' and 'FG', respectively (Fig. 4B and 4C). In ripe fruits following cold storage, peach cultivars 'FK' and 'MD' showed an increase in the amount of reducing, whereas in other cultivars amount of reducing sugars decreased in full ripe fruits following cold storage (Table 1). In early maturing peach cultivars, concentration of non-reducing sugars reduced with increase in cold storage period and fruit ripening; whereas, in late maturing cultivars, non-reducing sugars first increased up to 10 days of cold storage + 2 days of ripening and with increase in cold storage period the concentration of non-reducing sugars reduced in ripe fruits (Table 1). For changes in level of total sugars a similar trend was observed as noticed in the non-reducing sugars (Table 1). During fruit ripening before storage level of ascorbic acid reduced as fruit ripening progressed. On day-1of fruit ripening, the maximum level of ascorbic acid was observed in 'FG' peach fruits and the minimum in fruits of peach cultivar 'IB'. At fully ripe stage, peach cultivar 'FK' exhibited the highest level of ascorbic acid, whereas the lowest amount of ascorbic acid was observed in peach cultivar 'IB' (Fig. 5). In ripe fruits following 20 days of cold storage, level of ascorbic acid in peach cultivar 'FG' increased from 3.5 to 4.2 mg 100 g^{-1} fresh weight. Overall the level of ascorbic acid decreased with increase in the fruit storage and ripening period (Table 1).

DISCUSSION

Peaches being climacteric in nature undergo rapid fruit ripening processes that result in reduction of shelf life, even under cold storage. During ripening fruit produces ethylene, with higher rate of respiration, weight and firmness losses. Difference in weight loss among these cultivars may be due to their genotype. Earlier studies on peaches and nectarines showed that weight loss increased as fruit ripening and storage periods progressed (Akbudak and Eris, 2004; Zhou et al., 2002). Weight loss in fruits occurred as result of dehydration and loss of water from their surface. Our results confirm the findings of Zhang et al. (1996) and Ullah et al. (2015) who stated that fruits begin to reduce their weight and firmness soon after harvest when stored at room temperature. The probable reason might be the high respiration rate at relatively high temperature which lead to water and weight loss.

All peach cultivars exhibited significant reduction in fruit firmness during ripening before and following cold storage. Fruit softness is an important physiological process associated with fruit quality. It involves various structural as well as compositional changes in cell wall components as a result of action of fruit softening enzymes (Barrett and Gonzalez, 1994; Fischer and Bennett, 1991). Higher fruit firmness in peach cultivars 'PS-3' and 'IB' might be due to presence of insoluble protopectins and comparatively less amount of soluble protopectins. Fruits with higher softening resulted in conversion of insoluble protopectins to more soluble pectic acid and pectin. Peach cultivar 'FG' exhibited higher incidence of CI, as compared all other cultivars. Incidence of CI during storage of peaches might be due to the reason that when fruits are subjected to prolong low temperature, breakdown of the internal tissues

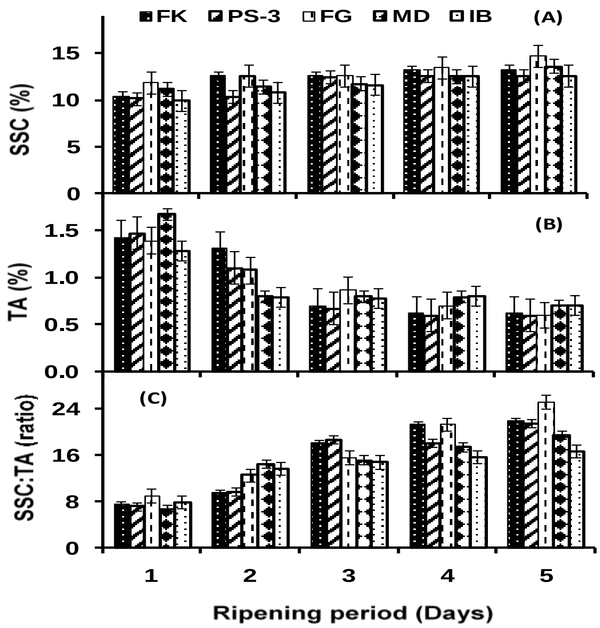

Figure 3: Changes in SSC (A), TA (B), and SSC: TA ratio during fruit ripening of different peach cultivars at ambient temperature. Vertical bars represent ±SE of means for three replicates.

increases mealiness in tissues internally which are ultimate symptoms of CI (Brummell et al., 2004). Exposure of fruits to low temperature cause modification in permeability of membranes and consequently lead to the cell autolysis, membrane imbalance, and development of CI symptoms due to conversion of liquid-crystalline to solid-gel structure (Wang, 1989). Higher level of CI in fruits of cultivar 'FG' may also ascribed to the higher fruit softening (Fig. 2). Softening of fruits occurs due to damage of cellular membrane integrity, which is associated with activity of polygalacturonase enzymes (Paliyath and Droillard, 1992). During fruit ripening, increase in activities of polygalactronase and pectin esterase enzymes cause depolymerization of pectin. Delayed and modified depolymerization and solubilization may lead to the partial reduction in the higher activities of major cell wall hydrolysis enzymes (Ali et al., 2004). Similarly, earlier Khan and Singh (2007) found that exogenous application of ethylene inhibitors to Japanese plum fruits suppressed their softening with reduced activities of cell wall hydrolytic enzymes including pectin esterase, exo- and endo-polygalacturonase, and endo-1,4-β-D-glucanase.

Level of SSC and SSC: TA ratio of peach fruits increased with progress in their ripening, however, significant variations were observed among the cultivars. Peach cultivar FG exhibited higher SSC and SSC: TA ratio and lower TA values in ripe fruits before and following cold storage (Fig. 3 and Table 1). This might be due to genetic factor and advanced rate of fruit ripening. Higher SSC: TA ratio is due to higher SSC and lower TA values. Reduction of acidity in other peach cultivars may be due to rapid rate of oxidative processes. Higher respiration may result in degradation of organic acid that confirm the earlier studies that organic acids act as substrates for enzymatic reactions of respiration that resulted in reduction in the acidity. Different

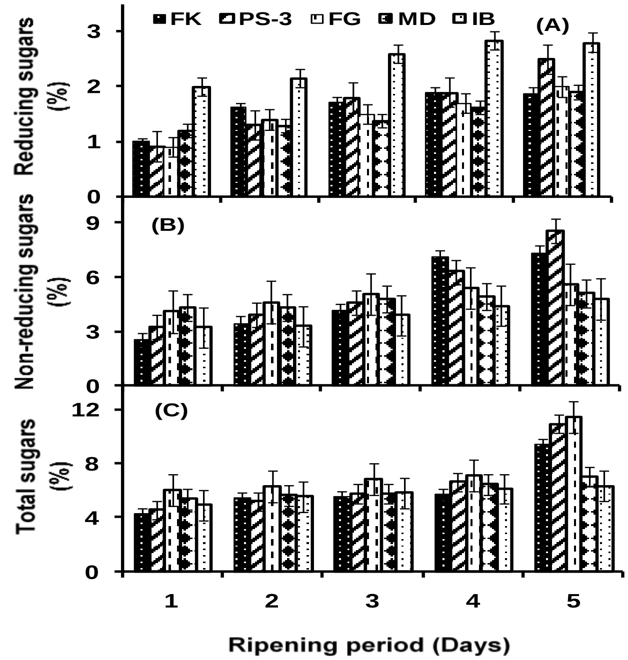

Figure 4: Changes in reducing sugars (A), non-reducing sugars (B) and total sugars (C) during fruit ripening of different peach cultivars at ambient temperature. Vertical bars represent ± SE of means for three replicates.

cultivars have different SSC ranges, so this distinction might be due to varietal character. These results found to be in close agreement with Liverani and Cangini (1991) who reported that SSC tend to be higher in white fleshed cultivars as compared to yellow fleshed ones. Differences found in the level of TA in the above cultivars might be due to their genetic makeup because different peach cultivars have different metabolic activities. Earlier it has been reported that European and American peach and nectarine cultivars are more acidic than cultivars originated from China (Moinng et al., 1998). Similarly, Wu et al. (2003) have found that level of acidity and ascorbic acid content in peach and nectarine decreased with increase in storage period.

Data about the levels of sugars in different peach cultivars were significantly influenced by fruit ripening and storage periods. Early maturing peach cultivar 'FG' showed the maximum total sugars followed by 'PS-3' and 'FK'. Late maturing cultivar 'IB' had the minimum total sugars followed by 'MD'. Earlier finding of Liverani and Cangini (1991) support our results and showed significant variations in sugar levels of white and yellow fleshed peach cultivars. Variation in reducing sugars in different maturing peach cultivars might be due to fructose, which is the main reducing sugar in most of fruits. Similarly, white fleshed cultivar 'Triestina' had been found to contain higher sucrose level, than yellow fleshed peaches (Liverani and Cangini, 1991). Variation among sugar contents in different season maturing peach cultivars might be due to difference in the environmental factors during fruit maturity. These results also confirm the findings of Crisosto et al. (1997) who reported that sugars content in peaches and nectarines may vary with cultivar, maturity and environmental conditions. It has been reported

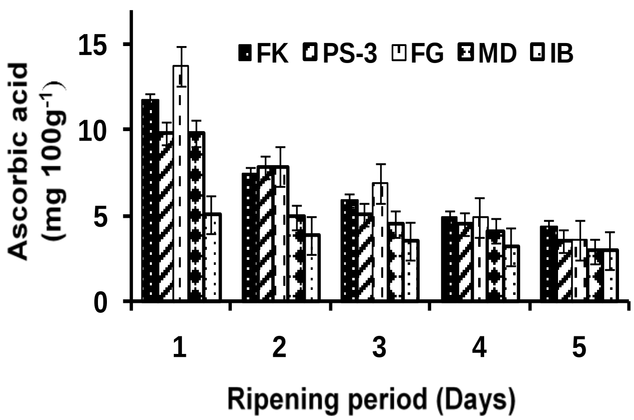

Figure 5: Changes in ascorbic acid content during fruit ripening of different peach cultivars at ambient temperature. Vertical bars represent ±SE of means for three replicates.

that level of total sugars increased with increase in storage period as the accumulation of sucrose and fructose increased with the passage of storage time (Wu et al., 2003).

Level of ascorbic acid in all peach cultivars showed decreasing trend as ripening period progressed (Fig. 5). Our results confirmed the earlier findings of Khan and Singh (2009) who observed that plum fruits showed decrease in ascorbic acid content with increase in storage period. Data regarding ascorbic acid showed highly significant results for different cultivars. Peach cultivar 'FG' exhibited the maximum ascorbic acid level followed by 'FK' and 'PS-3' at harvest, and cultivar 'FK' exhibited the highest level of ascorbic acid at ripe stage before and following cold storage (Table 1). Similarly, Wu et al. (2003) also reported that ascorbic acid content decreased with increase in the storage time. The maximum amount of ascorbic acids was recorded in early maturing cultivar 'FG' and the minimum in late maturing cultivars.

CONCLUSION

In the first experiment, peach cultivars. 'FG' (an early season maturing) and 'MD' (a late season maturing) showed better fruit quality during ripening at ambient conditions (30±2 °C with 60±5% RH) as compared to other peach cultivars. Whereas in second experiment, among all peach cultivars, 'IB' fruits stored best at 0±1 °C up to 20 days with lowest incidence of CI, higher fruit firmness, lower weight loss, as well as an acceptable SSC, SSC: TA ratio, ascorbic acid content, and total sugars.

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